CUMULUS CLOUD LINES VS. SURFACE WIND IN EQUATORIAL LATITUDES

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ABSTRACT

A large majority of cumulus cloud lines seen by the weather satellites ESSA 1 and ESSA 2 over the Atlantic and eastern Pacific Oceans, between the latitudes of 10° N. and 10° S., are approximately parallel to the surface wind direction. Although as yet undetermined with confidence, certain characteristics of the cloud lines themselves seem to indicate whether a cloud line is nearly parallel to or normal to the wind direction. A method is proposed for using the satellite observations of cumulus cloud lines as an aid to drawing streamlines in data-sparse areas.

1. INTRODUCTION

Surface weather analyses in equatorial latitudes usually depend upon a direct analysis of the wind field to portray atmospheric motions. At the Tropical Analysis Center (TAC), Miami, Fla., a streamline analysis of the wind field in the low latitudes is made routinely from pibal reports at a level above the friction layer and ship reports of surface wind. Because ship reports over the equatorial oceans are not usually sufficient to define the wind field, development of a method of using satellite observations of cumulus cloud lines to determine the surface wind direction was attempted. To the author's knowledge, no similar study has been published, although the relations of the low-level wind to cloud lines in the trade wind belt and for cold air outbreaks over relatively warm water have been studied [1], [2], [3], [4], [5]. Pertinent are the study by Schuetz and Fritz [1] who showed cloud streets aligned within 30° of the mean wind direction in the convective layer in a single case of TIROS-observed cumulus cloud streets over the Caribbean Sea, and the outstanding work by Malkus [2] in the Pacific, about which more will be said later.

In the region of concern, the Atlantic and eastern Pacific Oceans, between the latitudes of 10°N. and 10°S., there are few or no upper-air data for the lower troposphere on a current basis; and neither the vertical shear nor the presence or height of a temperature inversion can ordinarily be determined. Thus, the study must be of a statistical nature, and no attempt is made to explain why the cumulus cloud lines have the demonstrated relationship to the wind.

2. MATERIALS AND PROCEDURE

The major portion of the study was performed while the author was on a temporary duty assignment at the National Environmental Satellite Center (NESC), Washington, D.C., during April and May 1966. At the NESC, montages of the ESSA 1 satellite television photographs of the entire earth were available on a daily basis, and copies of the Miami TAC surface analyses were available for 0000 and 1200 GMT. All of the ESSA 1 montages over the oceans between 10°N. and 10°S. latitudes and from Africa westward to 130° W., which is the limit of the TAC charts, were examined. Areas with visible cloud lines were searched on the appropriate surface analyses for any data to indicate the surface wind. The TAC surface analyses include selected pibal reports at the 2,000-ft. level. If wind data were not available in or near the area of cloud lines, the case was discarded. When wind data were available, the direction and speed of the wind were estimated, and the orientation and characteristics of the cloud lines were noted. In general, the quality of the wind data was less than desired. Most often only one ship report was available in or near the area of cloud lines. Sometimes the wind could be interpolated between two or more ships or between a ship and a coastal station pibal, or it could be extrapolated from several coastal pibal reports. Cloud lines which appeared to consist of cumulonimbi were not considered as they might be more representative of a higher-level flow. Only cases which fell within 4 hr. of chart time were accepted. Admittedly the procedure was very subjective and the evidence in individual cases was often not convincing. However, the consistent manner in which the cases gave essentially the same result as they accumulated is considered to be good evidence of the quality of the comparisons and of the resulting conclusions.

In a case log (not included) after each case number, the ESSA 1 satellite pass number, the camera number, film frame number, time, and date were listed, with the location of the area of cloud lines to the nearest degree, the orientation of the lines, and usually a notation of their most prominent characteristics. Also listed were the date and time of the chart used for comparison, the estimate of the wind in the area of cloud lines, and a comment on how the estimate was made. The frame number was not always included because, for various reasons, the film was not always available. In a separate binder with the original manuscript were collected photo-

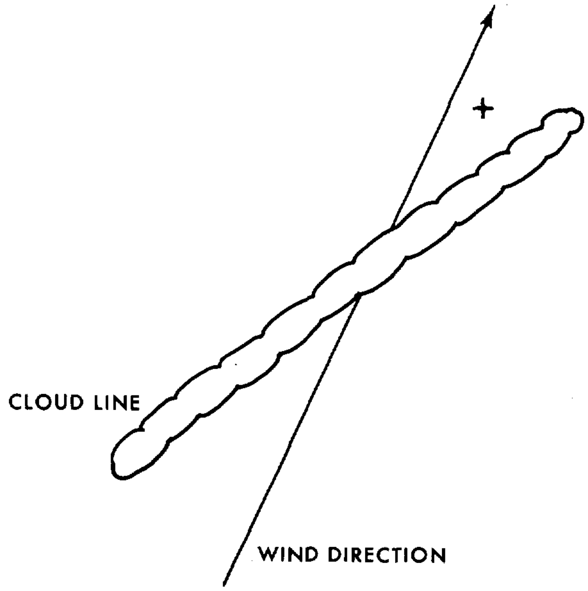


FIGURE 1.—A cloud line across the surface wind in the sense shown would give a positive acute angle; crossing in the other way would give a negative acute angle.

graphic prints for each case for which film was available and a copy of a small section of the chart showing the available wind data. For the sake of brevity, only a few selected cases are shown here. See figures 2–4.

3. CLASSIFICATION BY DIRECTION

Table 1 is a classification by direction of the cases through May 1966, based on ESSA 1 observations. Case number, cloud line orientation, and the estimated wind direction and speed are shown in the left-hand columns. The angle between the cloud lines and the wind direction is indicated in the right-hand columns. This angle is in the sense of the model shown in figure 1. Thus, a cloud line crossing the surface wind as shown would have a positive angle less than 90°; crossing in the opposite way would give a negative angle. A cloud line was considered to be in the "parallel mode" if it lay within 20° of the wind direction, and in the "normal mode" if it lay within 20° of a line normal to the wind direction. Those cases which fell outside these limits were considered as intermediate and of no value for the present study.

TABLE 1.—*Classification of cloud line orientation vs. wind direction. (All directions in degrees about a circle, speed in knots.)*

Case	Cloud line orienta-tion	Wind direction and speed	Normal							Modified-parallel: Parallel					Modified-parallel				Normal		
			90	80	70	60	50	40	30	20	10	00	10	20	30	40	50	60	70	80	90
1	300/120	110/10											x								
2	240/060	140/10		x																	
3	290/110	100/18											x								
4	310/130	100/15													x						
5	250/070	230/10												x							
6	240/060	080/20								x											
7	310/130	050/12																		x	
8	320/140	080/10																x			
9	250/070	090/08								x											
10	210/030	090/10				x															
11	330/150	090/08																x			
12	320/140	210/10			x																
13	360/180	180/10										x									
14	330/150	130/15												x							
15	300/120	080/10														x					
16	320/140	210/10			x																
17	230/050	210/10												x							
18	240/060	210/10													x						
19	240/060	240/10										x									
20	330/150	120/10													x						
21	200/020	190/10											x								
22	320/140	150/10							x												
23	320/140	060/18																		x	
24	210/030	210/10										x									
25	240/060	240/15										x									
26	220/040	150/08																	x		
27	230/050	020/08													x						
28	330/150	120/08													x						
29	300/120	130/10									x										
30	230/050	210/12												x							
31	320/140	120/15												x							
32	300/120	120/20										x									
33	250/070	140/10			x																
34	220/040	230/10																		x	
35	240/060	130/08			x																
36	240/060	220/10												x							
37	320/140	110/20													x						
38	320/140	030/15			x																
39	210/030	110/20		x																	
40	210/030	200/08											x								
41	320/140	140/10										x									

In the initial review (table 1), of a total of 41 cases 19 were in the parallel mode, 11 in the normal mode, and 11 intermediate. However, there was a decided preference for small positive angles, making it desirable to stretch the limits slightly in order to include cases within a positive angle of 30°; a "modified-parallel mode" is thus defined. Time did not allow a further breakdown to determine whether the turning would be in a different sense in opposite hemispheres. Hereafter, when parallel mode is indicated it will be understood to mean modified-parallel mode. Looking again at the classification by direction, we note 25 cases in the modified-parallel mode, 11 in the normal mode, and only 5 intermediate. We may further note that 36 cases are either in the modified-parallel or normal modes, with only 5 intermediate. Note also that, if chance alone were operating, we should expect equal numbers of parallel and normal modes, as opposed to intermediate, since the limits cover 180° or half a circle.

Although the sample is still quite small, the data do appear to suggest a strong association between wind direction and cloud line orientation. Lacking other information, one might expect the odds for a cloud line being either in the parallel or normal mode to be on the order of 7 to 1, and for it to be in the parallel mode of at least 2 to 1.

Table 2 is a classification of cases through June and July 1966 based on ESSA 1 nephanalyses prepared at the NESC and received on facsimile at Miami. These often show cumulus cloud lines, but of necessity not nearly as many as are actually observed. No attempt was made to classify these by actual direction, but only by the mode in which they were found. Note that for these months there were 32 parallel mode cases, 4 normal mode cases, and 9 intermediate.

Table 3 is a classification of cases through June and July 1966 based on ESSA 2 APT pictures received at

TABLE 2.—*Cumulus cloud lines as shown on ESSA 1 nephanalyses vs. surface wind (Pm = modified-parallel mode; N = normal mode; I = intermediate)*

Date (1966)	Time (GMT)		Location (°)		Cloud line orienta-tion	Wind direc-tion & speed	Mode		
	Satellite observa-tion	Surface Chart	Lati-tude	Long-itude			Pm	N	I
June 1	1443	1200	4N	8W	200/020	210/15	x		
9	2000	1800	7N	93W	230/050	240/15	x		
12	1456	1200	7S	14W	300/120	110/15	x		
13	1421	1200	1N	00W	180/360	190/20	x		
14	1346	1200	3N	4W	350/170	180/15	x		
15	1311	1200	0N	6E	210/030	160/12			x
16	1416	1200	8S	14W	300/120	110/10	x		
23	1330	1200	1N	0W	230/050	230/10	x		
24	1435	1200	2S	7W	230/050	150/15		x	
24	2117	2400	8N	109W	240/060	190/12			x
25	1540	1200	4S	31W	230/050	110/15		x	
26	1505	1200	8S	14W	310/130	100/20	x		
July 3	1419	1200	8S	13W	310/130	110/10	x		
3	1600	1200	4S	32W	260/080	120/10			x
3	1920	1800	6N	92W	220/040	200/10	x		
4	1524	1800	8S	16W	320/140	120/20	x		
4	2157	2400	3S	118W	310/130	160/10			x
6	2130	2400	2N	116W	230/050	140/05	x		
6	2130	2400	3S	123W	310/130	140/05	x		
7	1338	1200	5N	1E	200/020	200/15	x		
7	1519	1800	1S	21W	300/120	140/10	x		
7	1519	1800	8S	16W	300/120	100/20	x		
8	1624	1800	9N	55W	280/100	090/18	x		
9	1408	1200	5N	8W	220/040	190/10	x		
9	1408	1200	8S	14W	280/100	120/15	x		
10	1333	1200	3N	2W	230/040	210/15	x		
11	1438	1200	8S	2W	330/150	140/10	x		
12	1222	1200	1N	4W	350/170	150/15	x		
12	1403	1200	3N	2W	210/030	180/10	x		
12	1403	1800	4N	8W	220/040	180/15			x
13	1508	1800	3N	24W	330/150	170/15	x		
16	1502	1200	6N	22W	210/030	160/10			x
16	1643	1800	0N	45W	290/110	100/10	x		
16	2004	1800	4N	108W	200/020	100/10		x	
17	1929	1800	5N	84W	210/030	170/12			x
18	1352	1200	6S	8W	290/110	130/15	x		
19	1958	1800	3N	92W	220/040	200/15	x		
20	1923	1800	4N	86W	190/010	200/18	x		
23	1236	1200	0N	8E	190/010	210/15	x		
24	1522	1200	7N	27W	340/160	130/10	x		
24	1843	1800	8N	87W	220/040	250/10			x
24	2023	2400	3N	97W	200/020	180/15	x		
24	2023	2400	1N	101W	190/010	150/10			x
25	1948	1800	3N	88W	210/030	180/10	x		
25	2128	2400	2N	112W	230/050	130/10		x	
Total	----------	----------	--------	--------	----------	----------	32	4	9

TABLE 3.—*Cumulus cloud lines as seen by the ESSA 2 APT system vs. surface wind (Pm = modified-parallel mode; N = normal mode; I = intermediate)*

Date (1966)	Time (GMT)		Location (°)		Cloud line orienta-tion	Wind direction and speed	Mode		
	Satellite observa-tion	Surface chart	Latitude	Lon-gitude			Pm	N	I
June 6	1349	1800	12N	91W	240/060	260/15	x		
7	1049	1200	5N	27W	260/080	360/08		x	
7	1420	1200	4N	92W	250/070	220/10	x		
8	1501	1800	7N	100W	200/020	200/10	x		
10	1044	1200	8N	26W	280/100	260/05	x		
10	1225	1200	8N	57W	250/070	260/15	x		
10	1415	1200	3N	84W	230/050	220/15	x		
11	1259	1200	8N	64W	230/050	070/10	x		
12	1334	1200	5N	83W	210/030	250/12			x
13	1220	1200	7N	55W	260/080	080,15	x		
13	1409	1200	7N	87W	230/050	260/08	x		
15	1331	1200	8N	85W	260/080	280/05	x		
18	1133	1200	9N	57W	310'130	100/12	x		
24	1502	1800	7N	111W	230/050	180/10			x
25	1346	1800	7N	89W	180/360	200/18	x		
28	1343	1200	3N	81W	210/030	220/10	x		
28	1343	1200	8N	85W	260/080	250/05	x		
28	1536	1800	9N	104W	240/060	220/15	x		
29	1418	1200	8N	89W	230/050	190/12			x
30	1454	1800	8N	93W	220/050	230/12	x		
July 4	1339	1200	4N	85W	220/040	200/20	x		
17	1350	1200	6N	83W	250/070	230/05	x		
17	1350	1200	1N	87W	190/010	190/10	x		
21	1421	1200	3N	83W	190/010	210/12	x		
21	1421	1800	6N	86W	200/020	210/10	x		
22	1454	1800	1N	87W	190/010	190/10	x		
Total	----------	----------	--------	--------	----------	----------	22	1	3

Miami. Again no attempt was made to classify these by actual direction, but only by the mode in which they were found. Note that from the APT pictures for these months there were 22 parallel mode cases, 1 normal mode case, and 3 intermediate.

Although some of the cases collected at Miami from both ESSA 1 nephanalyses and ESSA 2 APT pictures for the same months are probably overlapping (lack of time did not allow a determination of this), still a considerable number of cases was added making a grand total of well in excess of 100 cases. *The most important finding appears to be that a very large majority of cumulus cloud lines in equatorial latitudes is in the parallel mode.* Whereas in the initial review the normal mode had been found to be more than twice as frequent as the intermediate, the cases collected at Miami showed just the opposite condition. Thus, no valid conclusion may be reached as to the frequency of occurrence of the normal mode, except that it is low.

4. CLASSIFICATION BY CHARACTERISTICS

A classification of the cloud lines by characteristics was made in the hope that distinctive characteristics could be found which would indicate the mode in which the lines occurred. Some characteristics were selected by experience as being quite common. Lines could be described as relatively long or short, relatively narrow or broad, of uniform width, with or without tapering ends, gently curved or straight, of a wavy or zig-zag character, and with knots (locally wide places along a line). A distinct impression was gained in the early stages of certain characteristics which did seem to distinguish parallel mode from normal mode cloud lines. A closer analysis later seemed to disprove these initial impressions. For this reason the classification itself will not be included here. Nevertheless, it is believed that the author's initial impressions have some validity and subsequent experience in the field has tended to support this view. For the benefit of future researchers and as a guide to tropical analysts using the method in the field these impressions will be set down here.

It was my impression that cloud lines that appeared to be very long, very narrow, and either wavy, zig-zag, or with knots were most often in the parallel mode. Those which appeared to be short, of uniform width, and with blunt ends were most often in the normal mode. However, all of these characteristics were found on occasion with both modes, and they should therefore be used with caution.

Considerable insight as to what is actually being observed is perhaps given by the work of Malkus [2]. It is my belief that the satellite frequently observes areas where cumulus cloud lines occur in both the parallel and normal modes (or, of course, the intermediate) together at the same time. Indeed, at least one such case was acutally included in the study. More often, however, the satellite camera is unable to resolve the smaller clouds of one mode

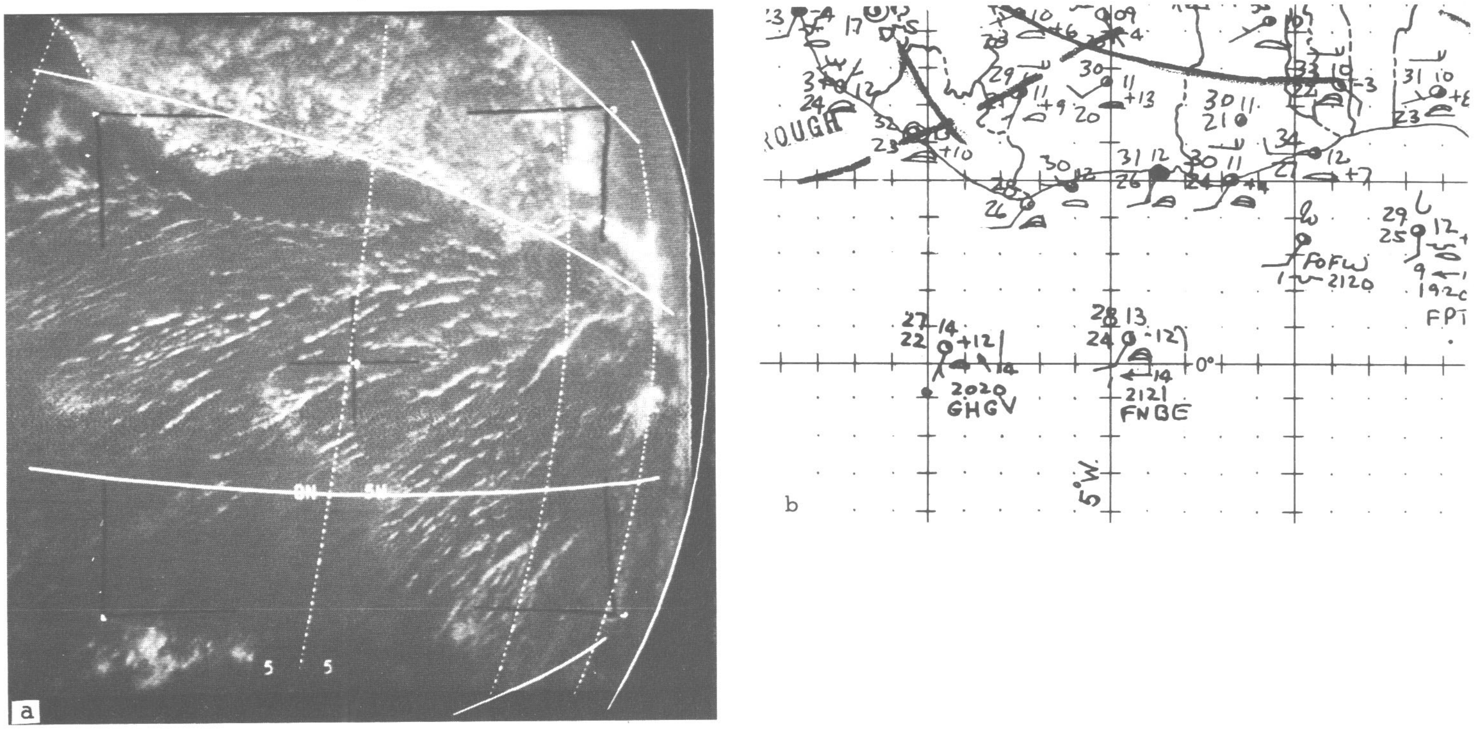


FIGURE 2.—Case 18: (A) ESSA 1 picture, 1441 GMT, March 19, 1966. (B) Chart for 1200 GMT, March 19, 1966.

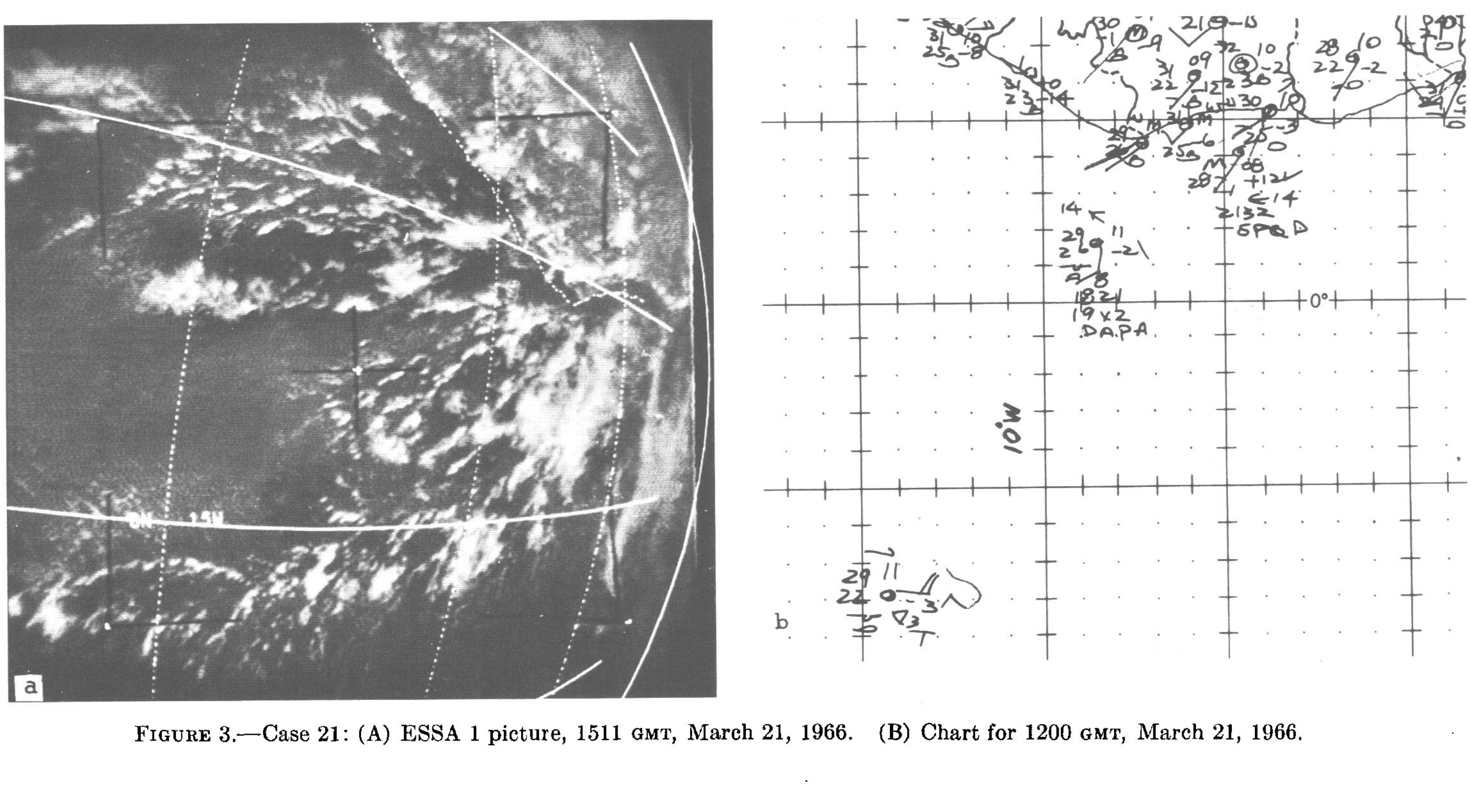
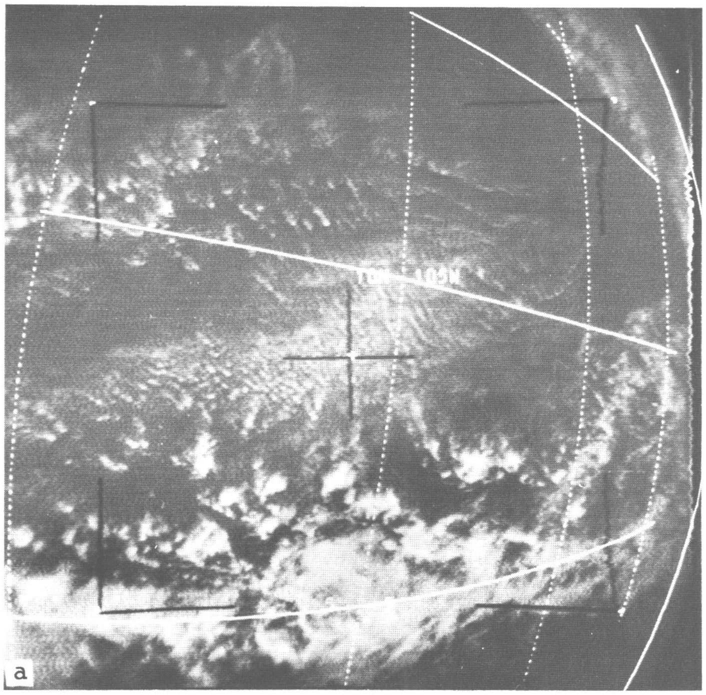


FIGURE 3.—Case 21: (A) ESSA 1 picture, 1511 GMT, March 21, 1966. (B) Chart for 1200 GMT, March 21, 1966.



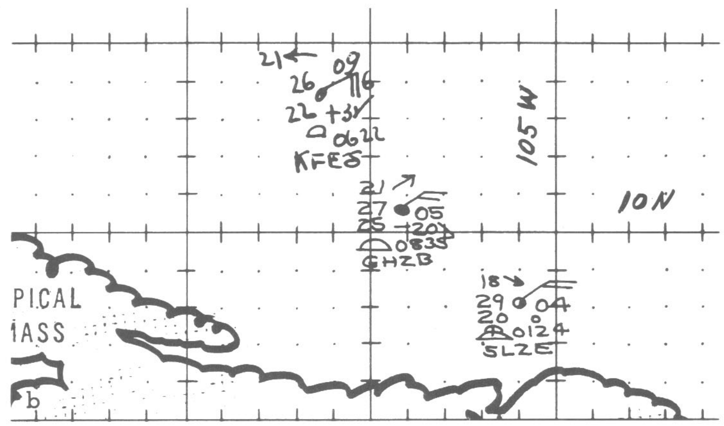


FIGURE 4.—Case 23: (A) ESSA 1 picture, 2119 GMT, March 22, 1966. (B) Chart for 0000 GMT, March 23, 1966.

and shows only the larger clouds of the "dominant" mode. These "dominant" mode cloud lines may be in either the parallel or normal mode, but in equatorial latitudes appear to be most commonly in the parallel mode. What appear to be "knots" or locally wide places along a cloud line may be points at which cloud lines in two modes intersect—the smaller lines are unresolved by the camera but reveal themselves as enlarged cloud masses where they cross the visible lines. Similarly, what appear as "zig-zag" lines (see fig. 2 near 2° N., 3° W.) may be alternating segments of lines in the parallel and normal modes, with different portions of adjacent lines visible successively. What I have called "wavy" lines may be in fact zig-zag lines as described above but less well resolved so as to give a rounded appearance to the points of intersection. It would be interesting to know why, if the above interpretation is correct, only successive segments of adjacent lines are visible to the satellite.

As a final remark on the above-described cumulus cloud line characteristics, I believe that further study might yield a reliable method of distinguishing cloud lines of one mode from those of another, and of determining which way, along or across the cloud lines, the wind is blowing. Other work is being done on this subject.

5. THE METHOD

It is proposed that the following practices be used to fill-in the streamline analyses where conventional data are lacking:

(1) Where cumulus cloud lines are evident on the APT satellite pictures, note their orientation and characteristics.

(2) Unless other data indicate otherwise, assume that the cloud lines are in either the parallel or normal mode.

(3) If the characteristics of the cloud lines do not give a good indication of modes, assume the lines to be in the parallel mode.

(4) The climatology of the region plus whatever peripheral data are available should indicate in what sense the streamlines should be drawn, either along or across the cloud lines. The analyst may make a slight adjustment to allow for the probable bias toward small positive angles in parallel mode situations.

(5) Intelligent departures from these rules should, of course, be made as the circumstances of each case dictate.

6. GEOGRAPHICAL DISTRIBUTION

Figures 5 a and b are, respectively, plots of the occurrence of cloud lines in the parallel or normal modes over the Atlantic and eastern Pacific Oceans. Cloud lines in the parallel mode appear to occur more frequently than for the sample as a whole over the region south of the normal position of the equatorial trough. Cloud lines in the normal mode appear to occur more frequently than for the sample as a whole in the region of the equatorial trough. Information of this sort should be gathered for any region of interest.

7. CAUTIONARY NOTE

When improved cameras are developed for future satellites and/or improved APT receiving equipment is available which will allow markedly better resolution of cloud elements than what is now possible with ESSA 1 or ESSA 2, the findings reported here may no longer apply.

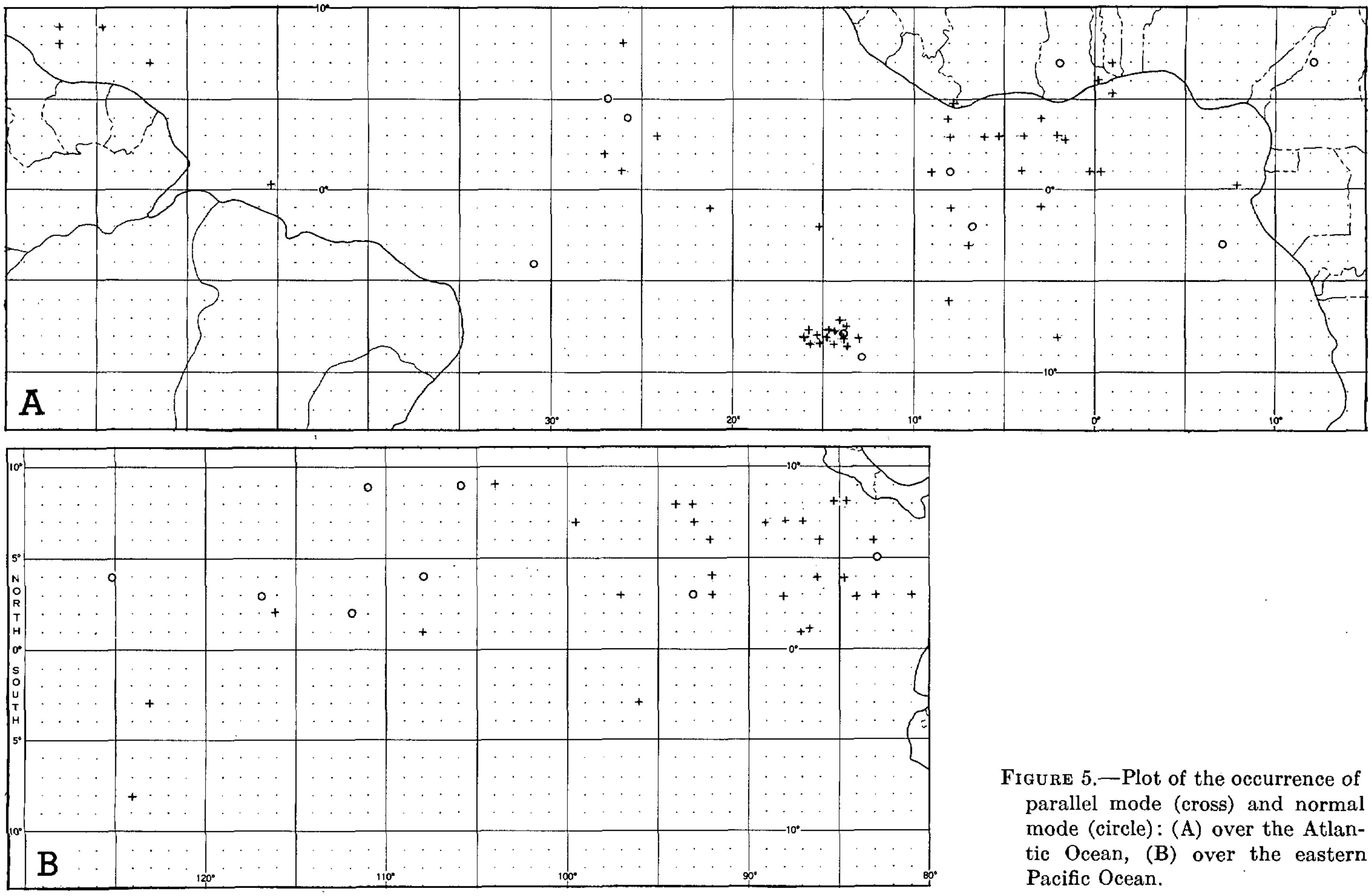


FIGURE 5.—Plot of the occurrence of parallel mode (cross) and normal mode (circle): (A) over the Atlantic Ocean, (B) over the eastern Pacific Ocean.

For example, the ratio of parallel mode to normal mode lines may appear quite different. Also, the results reported here for the equatorial latitudes of the Atlantic and eastern Pacific Oceans may not apply in other areas and the "Method" should be used only with caution.

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REFERENCES

1. J. Schuetz and S. Fritz, "Cloud Streets Over the Caribbean Sea," *Monthly Weather Review*, vol. 89, No. 10, Oct. 1961, pp. 375–382.
2. J. S. Malkus, "Cloud Patterns Over Tropical Oceans," *Science*, vol. 141, No. 3583, Aug. 30, 1963, pp. 767–778.
3. C. W. C. Rogers, "A Technique for Estimating Low-Level Wind Velocity from Satellite Photographs of Cellular Convection," *Journal of Applied Meteorology*, vol. 4, No. 3, June 1965, pp. 387–393.
4. H. M. Johnson and R. W. Fett, "Tropospheric Conditions Over the Tropical Atlantic as Observed by Two TIROS Satellites and Research Aircraft During September 22, 1966," *Meteorological Satellite Report* No. 29, U.S. Weather Bureau, June 1964.
5. J. C. Freeman, Jr., "Cloud Patterns. Part 2: A Mechanism That Organizes Cloud Patterns," *Monthly Weather Review*, vol. 91, Nos. 10–12, Oct.–Dec. 1963, pp. 630–632.

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